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RADARSAT ANTARCTIC MAPPING PROJECT

Antarctic Imaging Campaign - 2

A NASA Pathfinder Project

NAG5-9538

Year-1 Summary and Year-2 Budget Request

Prepared by:

The Ohio State University

Submitted to:

Dr. James Dodge

Dr. Waleed Abdalati

**The National Aeronautics and Space Administration Headquarters
Office of Earth Science**

May 21, 2001

Requested Amount for Year 2: \$752,951 and \$180,000 augment

Period: June 1, 2001 – May 31, 2002

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1.0 Introduction

The Radarsat Antarctic Mapping Project is a collaboration between NASA and the Canadian Space Agency to map Antarctica using synthetic aperture radar (SAR). The first Antarctic Mapping Mission (AMM-1) was successfully completed in October 1997. Data from the acquisition phase of the 1997 campaign have been used to achieve the primary goal of producing the first, high-resolution SAR image map of Antarctica. The limited amount of data suitable for interferometric analysis have also been used to produce remarkably detailed maps of surface velocity for a few selected regions. Most importantly, the results from AMM-1 are now available to the general science community in the form of various resolution, radiometrically calibrated and geometrically accurate image mosaics.

The second Antarctic imaging campaign occurred during the fall of 2000. Modified from AMM-1, the satellite remained in north looking mode during AMM-2 restricting coverage to regions north of about -80 degrees latitude. But AMM-2 utilized for the first time RADARSAT-1 fine beams providing an unprecedented opportunity to image many of Antarctica's fast glaciers whose extent was revealed through AMM-1 data. AMM-2 also captured extensive data suitable for interferometric analysis of the surface velocity field.

This report summarizes the science goals, mission objectives, and project status through the acquisition phase and the start of the processing phase. The reports describes the efforts of team members including Alaska SAR Facility, Jet Propulsion Laboratory, Vexcel Corporation, Goddard Space Flight Center, Wallops Flight Facility, Ohio State University, Environmental Research Institute of Michigan, White Sands Facility, Canadian Space Agency Mission Planning and Operations Groups, and the Antarctic Mapping Planning Group.

2.0 AMM-2 Project Definition

2.1 AMM-2 Science Goals

AMM-2 science goals are based on the polar related objectives of NASA's Earth Science Enterprise. These relate to understanding the mass balance of the polar ice sheets and the response of the polar ice sheets to changing climate. Specific science questions were selected whose answers could further progress towards reaching NASA's objectives and which could be addressed using the unique capabilities of RADARSAT-1. Science goals and questions are listed in table 1.

Table 1. AMM-2 Science Goals

<p style="text-align: center;">Ice Sheet Kinematics and Mass Balance</p> <ol style="list-style-type: none">1) How are the interior ice sheet and ice sheet margin changing?2) How are internal boundaries, such as the southerly limits of melt facies, changing?3) What are the velocities and strain rates for different flow regimes (ice streams, interior ice sheet, ice shelves)?4) What is the mass discharge from major drainage basins?5) Where are grounding lines located and have they moved? <p style="text-align: center;">Ice Sheet Dynamics and Ice Streams</p> <ol style="list-style-type: none">1) What are the morphologies and dynamic properties of Antarctic Ice Streams?2) What portion of the Antarctic Ice Sheet is drained by ice streams?3) How are ice sheet properties correlated with the glacier bed?
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2.2 AMM-2 Project Goals and Objectives

The AMM-2 has two project goals that follow from the science objectives and questions. The goals are listed in table 2.

Table 2 Project Goals

<ol style="list-style-type: none">1) Produce high-resolution image mosaics of Antarctica north of -80 degrees latitude for change detection measurements and studies to understand the response of the ice sheet to climate change2) Measure the surface velocity field over coherent and/or trackable areas of the ice sheet north of -80 degrees latitude for ice dynamics studies and for exploring the time varying nature of dynamical processes
--

The project goals lead to a list of primary and secondary project objectives, which are summarized in tables 3 and 4. The secondary objectives fall outside of the original Pathfinder proposal and were developed subsequent to the detailed evolution of the project concept and mission plan. Nevertheless, they are worthwhile objectives that will be addressed pending availability of time and resources.

Table 3. Primary Objectives

- 1) Production of a 25 m, image map of the viewable area.
- 2) Production of 200 m, coherence maps of the viewable area.
- 3) Production of 5 km post spacing velocity field of coherent or trackable areas.
- 4) Production of 1 km post spacing velocity field of coherent or trackable areas of fast glaciers.
- 5) Production of 500 m post spacing velocity field along the grounding line.
- 6) Delivery of products to the DAACs.

Table 4. Secondary Objectives

- 1) Production of ascending and descending image mosaics of viewable area.
- 2) Production of high resolution, F1 ascending and descending image mosaics of fast glaciers.
- 3) Production of ascending and descending coherence maps of viewable area.
- 4) Production of F1 ascending and descending coherence maps of fast glaciers.

2.3 Acquisition Phase Objectives

The science goals and objectives lead to a set of acquisition phase objectives. These objectives form the basis of the mission requirements, acquisition plan and replanning strategies.

Table 5. Acquisition Phase Objectives

- 1) 1 complete image coverage of the viewable area for change detection.
- 2) 1 complete ascending image coverage of the viewable area.
- 3) 1 complete descending image coverage of the viewable area.
- 4) 1 complete set of F1 image mini mosaics over high velocity areas.
- 5) 1 complete set of ascending F1 image mini mosaics.
- 6) 1 complete set of descending F1 image mini mosaics.
- 7) 1 F1 image pair for InSAR and feature-retracking velocity over fast glacier polygons.
- 8) A standard InSAR ascending and a descending pair for velocity over remaining areas.
- 9) 3rd cycle of standard and fine images for double differencing and remapping to improve single pair InSAR success rate and velocity coverage.

3.0 Acquisition Phase Summary

3.1 Pre Acquisition Phase Activities

AMM-2 project scope was established during a series of meetings during the winter of 1999/2000. The project was discussed at NASA HQ in late October 1999 and then during a RADARSAT International Steering Committee meeting in November 1999. At the ISC meeting, CSA described satellite health and in particular, complications with the

satellite prime pitch wheel, one of the S-band transmitters, and the second horizon scanner. Based on satellite health and safety, CSA expressed reservations about proceeding with a second south mode acquisition campaign and recommended that NASA consider north mode acquisition options. NASA continued to pursue a south mode campaign but requested that the project also investigate other options. Subsequent discussions resulted in a compromise AMM-2 plan consisting of either two north mode, INSAR acquisitions in 2000 and 2001, or one south-mode campaign in 2003 and after launch of Radarsat-2. The plan was discussed at the January 2000 ASF UWG meeting and endorsed by the follow-on Antarctic Mapping Planning Group meeting.

The project reviewed the implications of this strategy and presented a revised approach to CSA and NASA in early February 2000. Based on the expected lifetime of the satellite, the recommended approach focused on intensive, north-mode interferometric coverage in 2000 and 2001. NASA requested that the project begin immediate preparations for a 2000 campaign.

Planning consisted of several elements. The Jet Propulsion Laboratory developed the AMM-2 acquisition plan. The plan was designed to achieve acquisition phase objectives and to optimize the use of satellite and ground station resources. With regard to the former, the plan established 3, identical acquisition cycles for interferometric purposes. The plan also utilized RADARSAT fine beams for imaging faster glaciers. This approach improved chances for obtaining velocity data over fast glaciers either by using interferometry or feature retracking methods. With regard to satellite resources, the original plan relied on maximizing real time downlinks to the McMurdo Ground Station (Svalbard was also considered as a potential OBR downlinking site but was eventually discarded because of its licensing status with CSA). Consequently, the plan called for a significant increase in the amount of data destined for MGS as compared to AMM-1. Because MGS had failed early in the AMM-1 mission, procedures for doing early validation of MGS data were established. The procedures involved TDRSS/DOMSAT data transmission from the Antarctic to JPL via White Sands.

In addition to planning the acquisition sequence, orbit maintenance procedures were reviewed in the context of interferometric requirements. NASA HQ requested that JPL review the likelihood of successful RADARSAT InSAR acquisitions during a period of expected solar flux variability. The technical team report was negative. Independent discussions between the AMM-2 project, JPL engineers and the CSA flight operations group painted a more optimistic picture. These suggested that an improved orbit determination procedure coupled with a flexible orbit maintenance strategy could be developed that achieved nominal interferometric baselines. Later analyses determined that CSA orbit determination procedure was adequate. Orbit maintenance strategy details were refined throughout the planning phase and converged on a hybrid between frequent micro-maneuvers and time-targeted maneuvers. The objective was to maintain the satellite track within a narrower (500 m to 1km) guard band about the nominal track. This would be achieved with 7 to 10 day maneuvers (short shoot to minimize reaction time if burn occurs during unexpectedly low solar drag). It was only near the end of the planning activity that details for properly phasing the burns was worked out. In essence,

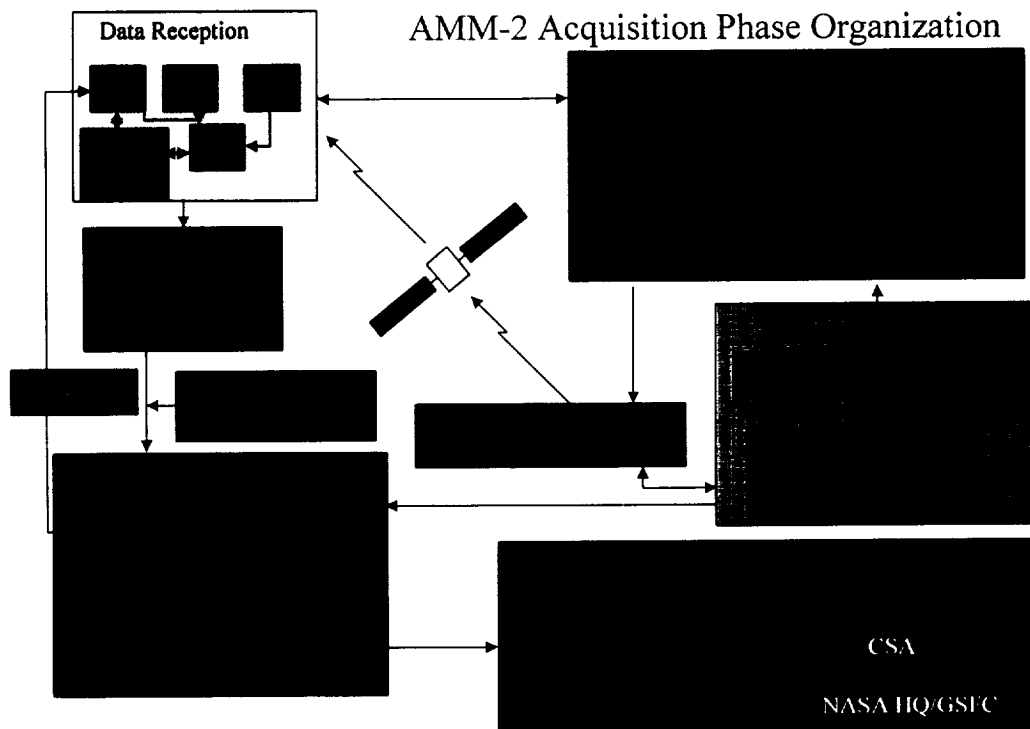
burns would target times to maximize similarities between successive orbit displacement parabolas.

Work on the RADARSAT Antarctic Mapping System -2 concurrently began at Vexcel. The Functional Requirements Document was reviewed in late April 2000. A list of all acquisition phase documentation was also compiled. A mid-May meeting at JPL to review the status of acquisition planning followed this meeting. At that time, the project was introduced to the JPL automated mission planning system, ASPEN. ASPEN analyses affirmed the quality of the acquisition plan largely created using the CSA SPA and additional custom software created by JPL.

AMM-2 project requirements and documentation were formalized at a project review convened at the Alaska SAR Facility in June 2000. Along with summarizing end-to-end project status, the review concentrated on ground station preparations at ASF and MGS and end-to-end data and information flow.

CSA and NASA convened a readiness review at CSA in early August. There was enough uncertainty in the ground network activities that an end-to-end system test was scheduled for mid-August with a delta readiness review scheduled for the end of August. These reviews proceeded satisfactorily.

The ensemble of acquisition phase organizations is shown in figure 1.



3.2 Acquisition Phase

OSU personnel were deployed to ASF (Noltimier), PSS (Munk) and GSS (Zhao) at the start of the acquisition phase. Munk and Zhao were responsible for reporting on cycle 1 acquisitions and data quality at each station respectively. Noltimier was responsible for tracking data quality and acquisitions at ASF during all three cycles. Jezek joined the JPL planners (Austin) at CSA prior to the start of acquisitions.

Cycle 1 acquisitions began on September 3. OBR and RTM data were successfully acquired. MGS data were transmitted via TDRSS and DOMSAT for evaluation at JPL (Joughin). ASF processed quick look and Level Zero data for evaluation by the science team members at OSU and the University of Utah. RSI provided Level Zero data from acquisitions at Gatineau for science team members at CCRS. For several days, acquisitions proceeded flawlessly.

On Sept. 8, MGS reported a tape recorder problem. Data were acquired on the main recorder but lost on backup. MGS solved the problem with simple system reset and no data were lost. MGS reported a data loss on September 9. Signal levels were observed to fall to the noise level during an acquisition. Antenna data files were examined at ASF, WFF, and CSA but the nature of the problem was undetermined. MGS reported a major system failure on Sept 20 and passes were lost. Per agreement, CSA switched acquisitions from RTM to OBR while MGS attempted to solve the problem. On Sept 21, MGS reported that the torque limiter key failed. MGS refashioned a key and by Sept 22, MGS reported it was back on line after replacing the key. 13 data segments or about 18 minutes of data were lost due to this outage. On Sept 24 MGS reported that a storm resulted in power failures to the antenna. At this point, data acquisitions were again switched from RTM to OBR. Weather precluded attempts to fix the antenna for several days. In all 8 acquisitions were lost and 13 were subsequently reported as noisy. Other acquisitions were suspect. CSA begins to switch data from RTM to OBR. CSA also requested that ASF send updated WOS to MGS to keep MGS informed of the downlink schedule changes.

The MGS situation was discussed at the Cycle 1 review convened on September 27. As MGS reported no improvement, CSA began replanning data to OBR on a day-by-day basis. On Sept 28, WFF reported that the MGS problem was isolated and requested that CSA schedule test downlinks. The tests failed and so CSA continued to place as much data on OBR as possible and on a day-to-day basis. MGS subsequently reported that they could successfully acquire data in program track mode with manual intervention. Manual intervention was needed because MGS ephemeris data were infrequently updated. MGS continued to work the problem through October 10 when MGS reported successful RADARSAT-1 data takes.

The Oct 12 MAMM InSAR review was held on October 12 and MGS was reported as operational (although there are lingering problems outside of the main data acquisitions system). The team planned to gradually increase downlinks over the next few days. On

Oct 16, GSFC reported at the daily telecon that MGS suffered autotracking problems over the weekend and was only able to program track. No reports on data losses were provided prior to the report. Hence additional data were lost.

From October 17 to the 21, MGS acquired data in program track mode. Cycle 2 progress was reviewed on October 20. At that time, CSA suggested that it would take steps as necessary to secure the remaining Cycle 3 data. In return for those efforts, the project would consider CSA to have fulfilled its obligations towards AMM-2. On October 22 (just after the start of cycle 3), MGS reported a failure of the drive train axis. CSA rescheduled all data to OBR through the conclusion of cycle 3. Cycle 3 status was reviewed on November 2 and a final review was held via telecon on November 22. At that time, CSA offered to acquire a limited amount of cycle 4 data to fill any data gaps. The project accepted that offer and scheduled several additional data collections.

In addition to the problems at McMurdo, a handful of data was lost at each of the northern hemisphere ground receiving stations. A small amount of data were lost due to spacecraft anomalies. Some additional data were lost due to incompatibilities between acquisitions scheduling files.

3.3 Acquisition Phase Assessment

In spite of the ground segment failure, much of the AMM-2 planned data were captured. The success must be credited to the efforts of the CSA mission planners who worked long hours revising acquisitions schedules on a day-to-day basis for almost 2 straight months. Credit is also due to ASF which worked closely with MGS and to advise MGS of rescheduling activities. Also notable were the efforts of the MGS ground station crew and the WFF scheduling team who made considerable effort to solve difficult problems. Unfortunately, the problems may be systemic in that facility and the support structure established through WFF. JPL, GSFC and White Sands made significant contributions to knowledge about MGS data quality through analyses of data transmitted to JPL via TDRSS and DOMSAT.

AMM-2 planned acquisition times are summarized in figure 2. AMM-1 acquisition times are shown for comparison. AMM-2 times are estimated on the based available information. This means that ASF produced Scan Results Files are confirmed for all data takes identified as successful (save 8 outstanding passes). However, the durations of the data takes contained within the SRFs have not yet been compared to the planned times. So the mission summary times are based on planned durations only.

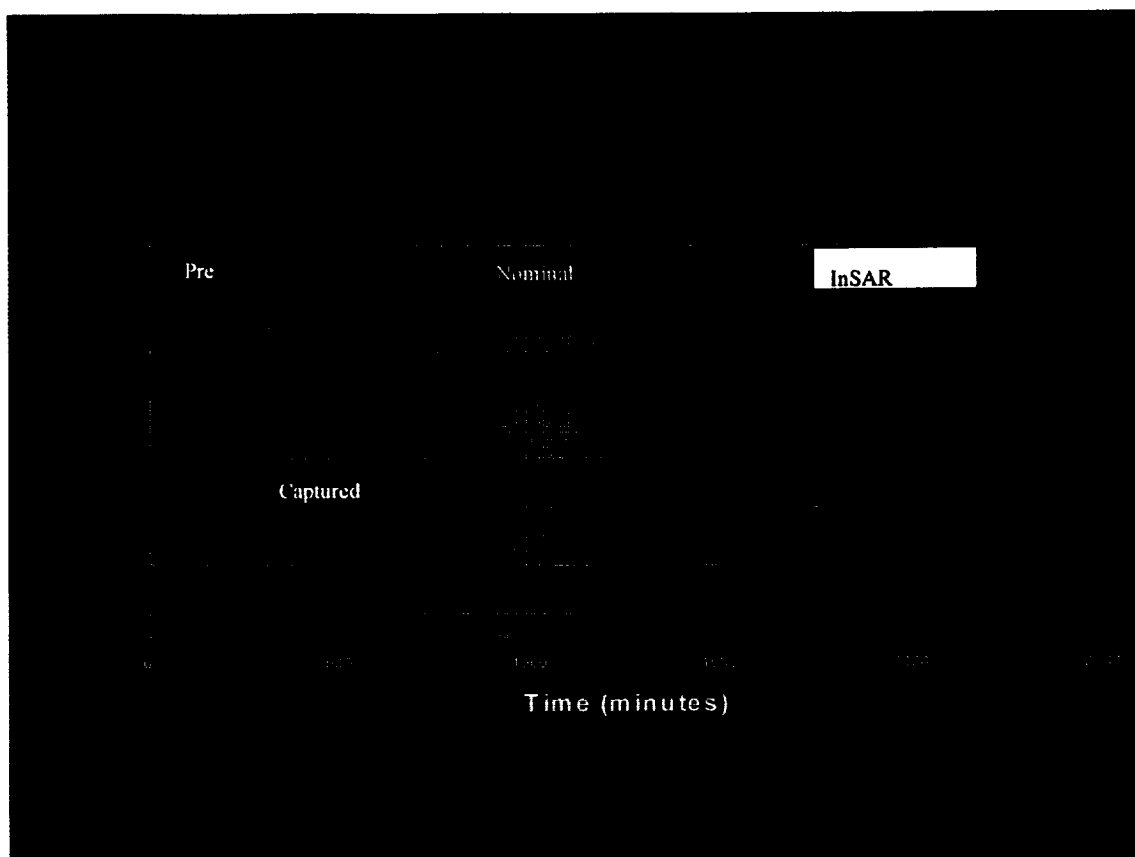


Figure 2. Acquisition Time Summary. AMM-2 acquired cycle times shown in blue and lost shown in red.

With the same caveat about acquisition knowledge, the total mission coverage is shown in figure 3.

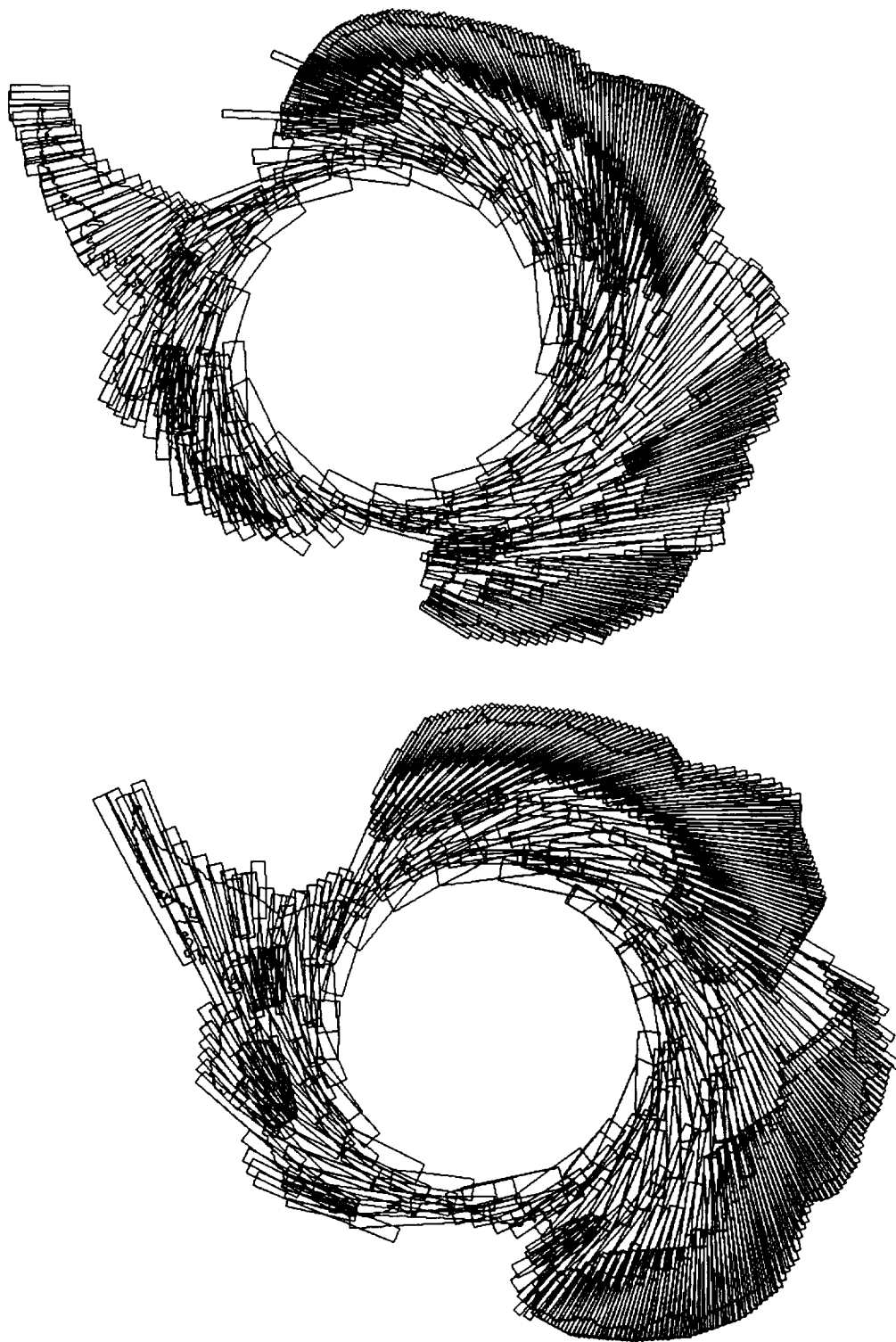


Figure 3. Ascending (top) and Descending (bottom) Mode Coverage Maps

Satellite repeat baselines and Doppler centroid control are the two other parameters that determine acquisition success. Ascending and descending baselines estimated from satellite ephemeris data are shown in figures 4 and 5. As the figure illustrates, the CSA flight dynamics team was very successful in maintaining baselines to less than 500 m. Larger baselines at more northerly latitudes are offset by the substantial use of F1 coverage near the coast. Because of the wider system bandwidth relative to standard beams, F1 repeat pass data can be correlated even when the baselines become larger than several hundred meters.

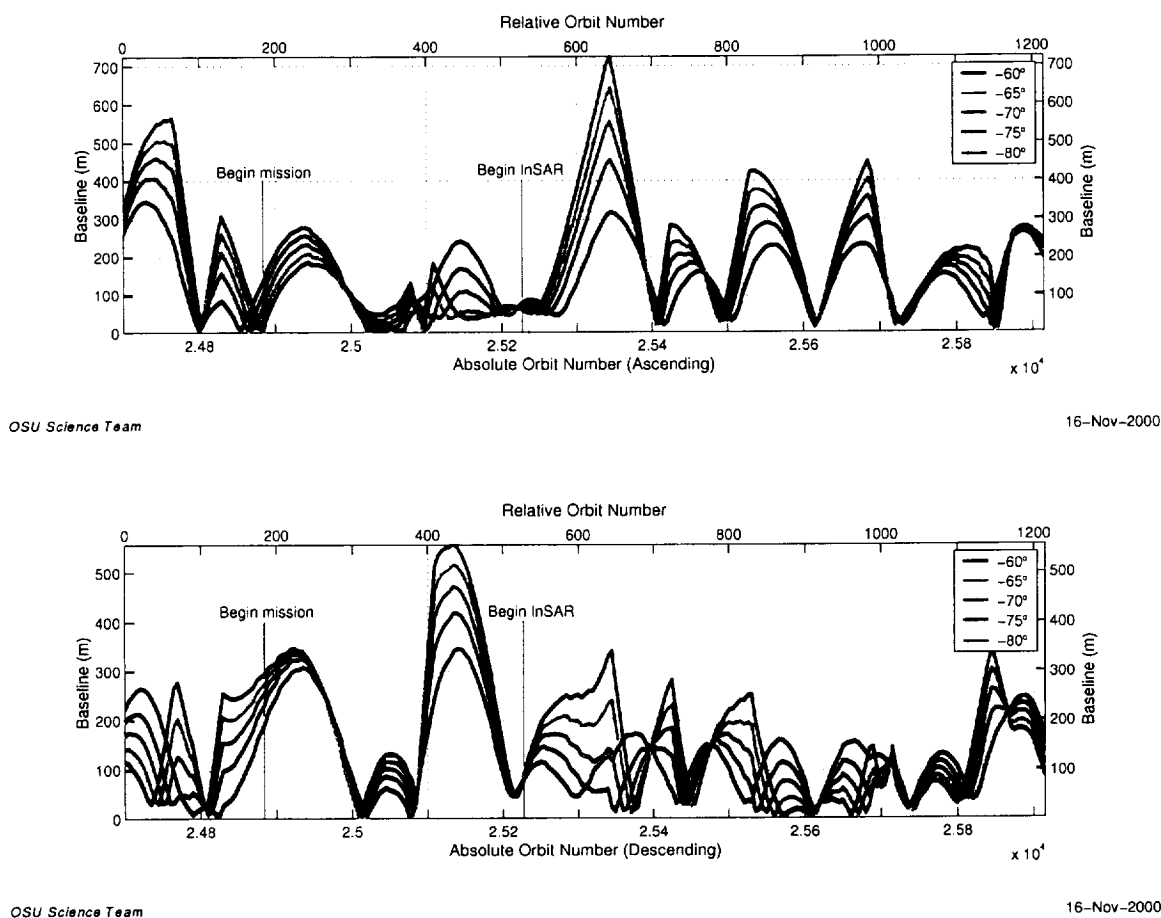


Figure 4 Cycle 1 and 2 Baselines

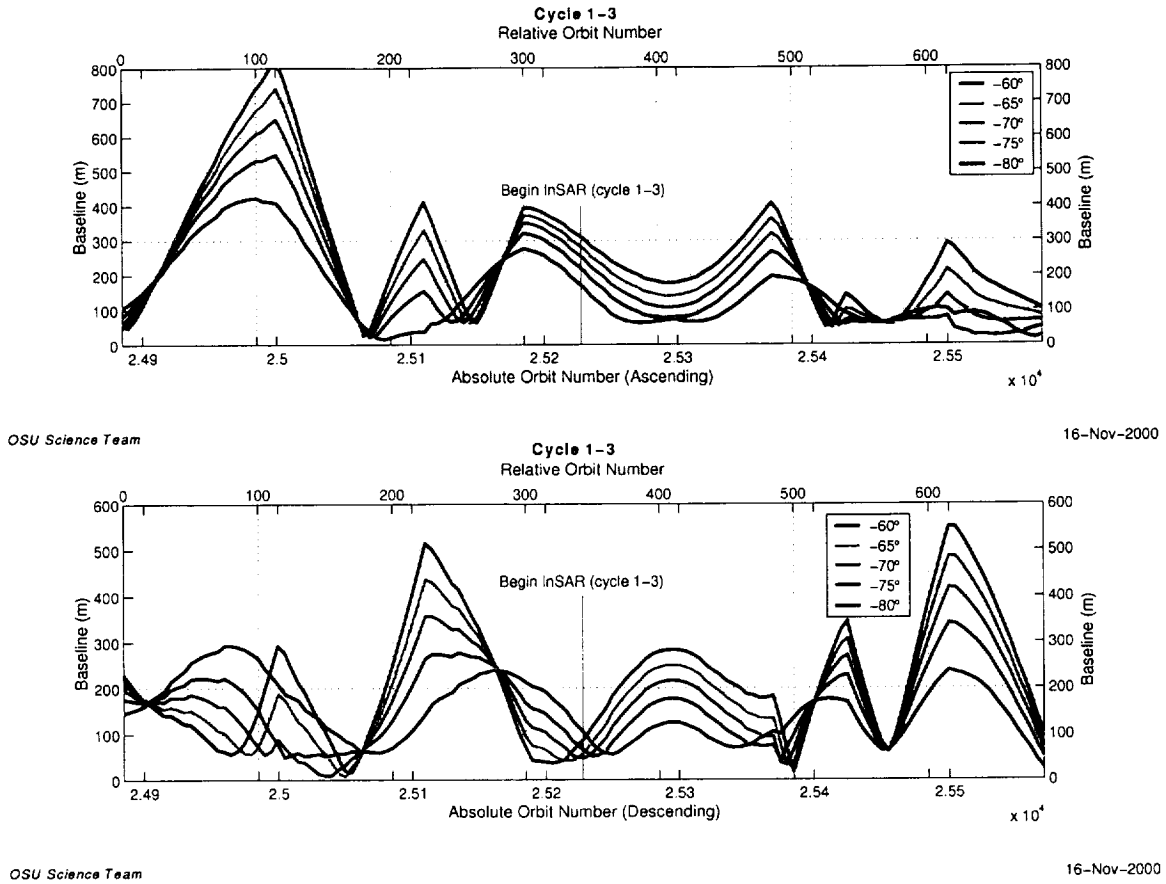


Figure 5. Cycle 1 and 3 Baselines

Interferograms are produced from information contained in the overlapping portion of the Doppler spectra from two passes. Ideally, the Doppler overlap should be several hundred hertz. For reasons yet to be understood, the Doppler overlap was smaller for AMM-2 data than was observed in AMM-1 data. Hypothetically, this may be due to reduced yaw control resulting from more frequent satellite maneuvers (one about every 10-12 days) needed to compensate for variability in solar drag. Alternatively, slight rotation of the orbital plane (as suggested by the baseline behavior with increasing latitude) may be a factor. Fortunately, we have found that data with only a couple of hundred hertz Doppler overlap are correlatable if the signal data are processed to the largest possible Doppler bandwidth (equivalent to the PRF). This is demonstrated by an example of the quality of interferometrically derived velocities shown in section 5.0.

In conclusion, available data indicate that acquisition coverage goals and InSAR acquisitions goals were met.

4.0 Data Production Phase

The production phase has several objectives including: scanning the data; processing the raw data to Level 0 and associated metadata products; creating revised parameter files

(PAR files) and chop files based on the data quality; processing the data to single-look, calibrated, complex images; creating image mosaics, coherence mosaics and interferograms; computing surface velocities using the interferograms and speckle retracking offsets. To meet the objectives, ASF has developed a processing system that integrates Vexcel Level 0 and Level 1 processors with ASF production, planning and archiving systems. Vexcel is developing modifications to the RADARSAT-1 Antarctic Mapping System (RAMS-2) for use by OSU.

Since January 2001, the project has been focusing on the first few steps leading to the delivery of SLC products to OSU in June 2001. A project status review was convened at Vexcel in January. ASF reviewed production schedules and Vexcel presented RAMS-2 development progress. Further discussion revealed that the characteristics of the AMM-2 data set required modifications to the original RAMS-2 design plan. In particular, the narrow Doppler bandwidth overlap observed for the data had several implications. First, the SAR processor bandwidth would need to be optimized for each data segment. This meant that the RAMS-2 frame-planning tool would have to preassign processor bandwidth and frame lengths via a modified PAR and CHOP file to be sent from OSU to ASF prior to Level 1 processing. Second, in cases where the processor bandwidth was widened beyond the point where Doppler artifacts became noticeable in the image data, a secondary post-processing filtering of the image data was required to narrow the Doppler bandwidth to approximately 900 Hz.

ASF convened a more detailed review of the processing status in April at Fairbanks. ASF presented an overview of the processing stream and discussed the processing schedule. A complete summary of the meeting is contained in the minutes which detail problems uncovered in Level 0 data. Progress was made on finalizing a set of project documentation for the processing phase. The documentation complements the package assembled in June 2000 for the acquisition phase. The revised calibration plan is the only outstanding piece of documentation.

Vexcel convened a RAMS-2 status review at Vexcel in May 3. An InSAR workshop and Antarctic Mapping Planning Group (AMPG) meeting followed the status review. Vexcel demonstrated progress on creating interferogram and coherence strips with the data. An outstanding action of the meeting is to address additional resource requirements identified by Vexcel. ASF summarized production status including resolution of several outstanding Level Zero issues. ASF also presented an updated production schedule. Together, the team assembled the following schedule for the early production phase shown in table 7.

Table 7. Schedule Through the Start of Production	
May 7	OSU assemble L0 processing queue request
May 9	L0 production begins at ASF (pending resolution of LZIP issues)
May 24	Planning tool is delivered by Vexcel to OSU
June 4	Operations Simulation
June 5	OSU starts PAR and CHOP file production
June 8	Vexcel and OSU complete SLC product validation
June 13	ASF begins routine SLC production
July 7	RAMS delivery at OSU (intallation/testing/training)

In mid-May, the project reviewed ERIM's progress in obtaining velocity control points. Velocity data were acquired for 9 sites around Antarctica. Results will be verified with using independent data for one of the sites, Byrd Glacier. Additional sites were identified in the interior of Antarctica and a method for measuring surface velocities was proposed. Should interior sites prove problematic, sites near stationary targets will be chosen. The site selection strategy will dictate that control sites solve phase unwrapping problems across, for example, ice stream shear margins.

Processing flow for Phase 1 is illustrated in figure 5.

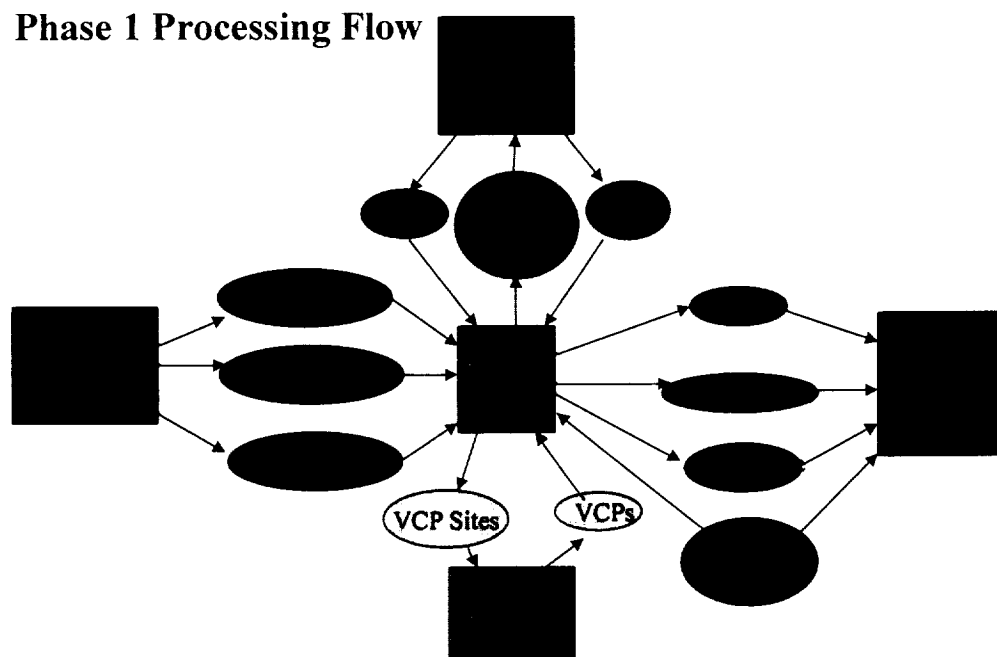


Figure 5. Phase 1 Processing Flow: Mosaic assembly

5.0 Early Science Results

5.1 Change Detection

Even over just three years, the Antarctic ice sheet can change appreciably. Some of the most dramatic changes on the continent are occurring along the Antarctic Peninsula imaged in 2000 by RADARSAT-1 (figure 6). The results document the continued retreat of the northern Larsen Ice Shelf, which south of Seal Nunataks, retreated over 30 km in just three years. But this is not the whole story. Segments of the ice sheet margin advanced during this period as well, including the entire front of the Amery Ice Shelf. The observed spatial variability of ice margin behavior hints at the complexity of understanding the forces effecting ice sheet advance/retreat. The RADARSAT data provide the first, repeated, high-resolution observations of the ice margin. These data will help determine whether local changes represent expected, episodic behavior or whether they represent regional trends driven by changing climate.

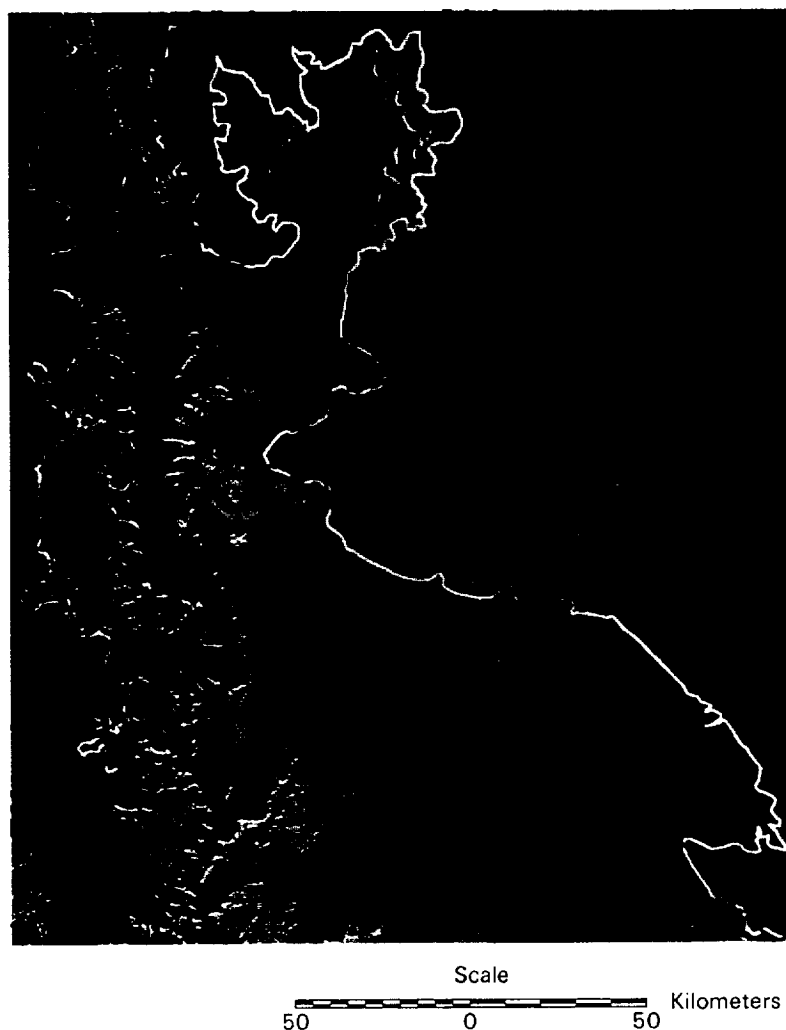


Figure 6. Antarctic Peninsula Ice Shelves. Coastlines represent: yellow - mid 1970's; red - 1992; green - 1997; image - 2000

5.2 Lambert Glacier Velocity

Using RADARSAT interferometric data obtained during the 2000 Antarctic Mapping Mission, ice velocity vectors were obtained over the Lambert Glacier. The areas of low to no motion (yellow) are either exposed land or stationary ice. The smaller confluent glaciers have generally low velocities (green, 100-300 meters per year) which gradually increase as they flow down the rapidly changing continental slope into the upper reaches of the faster flowing Lambert Glacier. Most of the Lambert itself has velocities between 400-800 meters per year, with a slight slowing in the middle section. As the glacier extends across Amery Ice Shelf, velocities increase up to 1000-1200 meters per year as the ice sheet spreads out and thins.

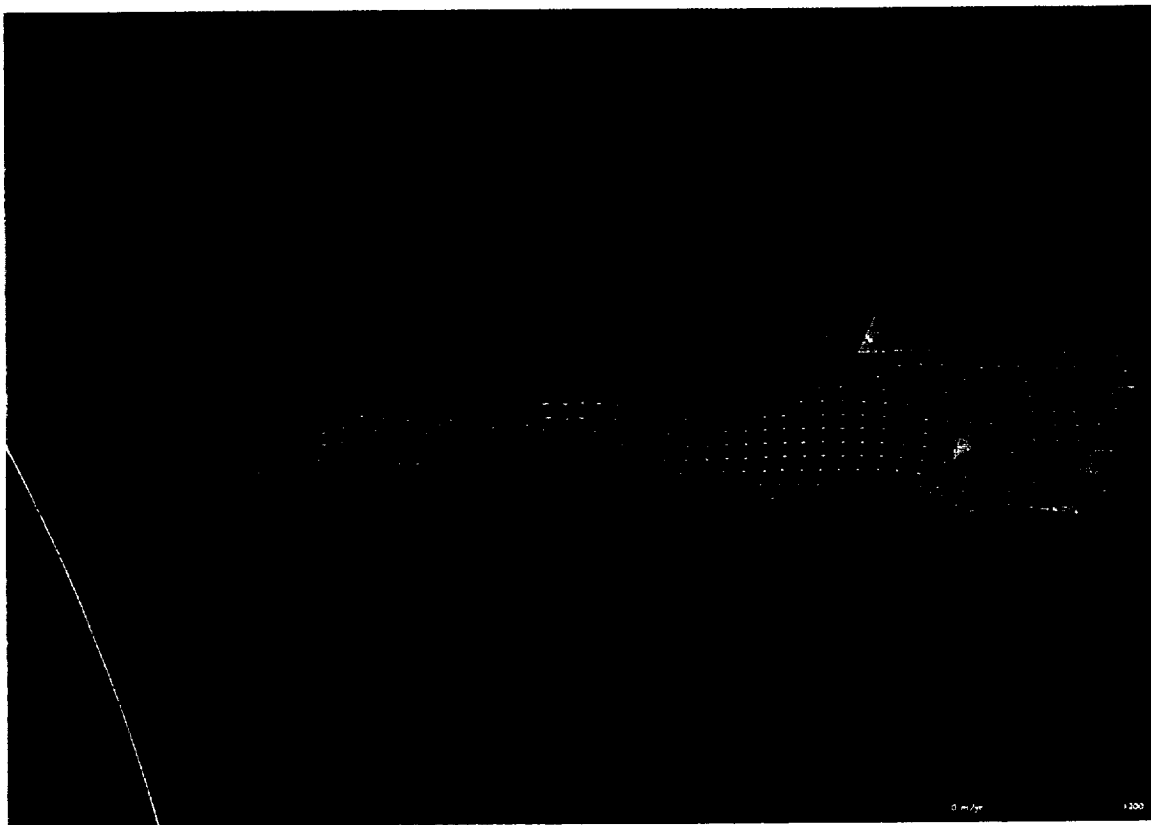


Figure 7. Lambert Glacier Velocities

In addition to these science results, JPL released information to the press about AMM-2 in February 2001. Antarctic Mapping Project results were summarized in an invited paper presented to the US Government SAR Users Workshop held at the Canadian Embassy in Washington during March 2001. AMM-2 is also featured in the CSA Annual Report for 2000/2001.

6.0 Plans for Year 2

OSU will begin creating PAR and CHOP files for ASF in late May. This will continue through the end of the calendar year.

ASF SLC production will begin in mid-June. F1 production will be complete by mid-November. All data will be processed by March 2002.

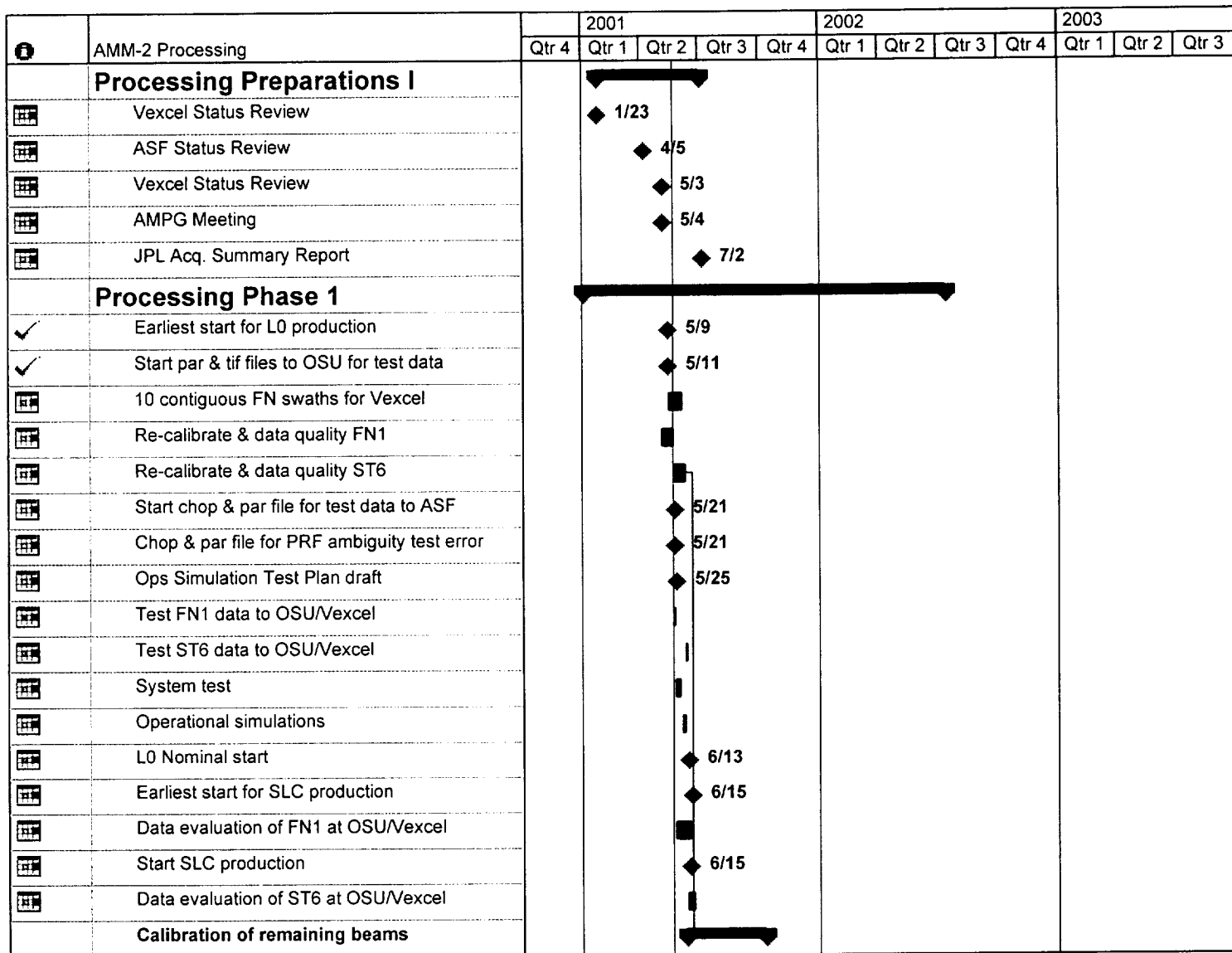
Vexcel will deliver and install RAMS-2 Phase 1 in mid July. Acceptance testing will occur through early August.

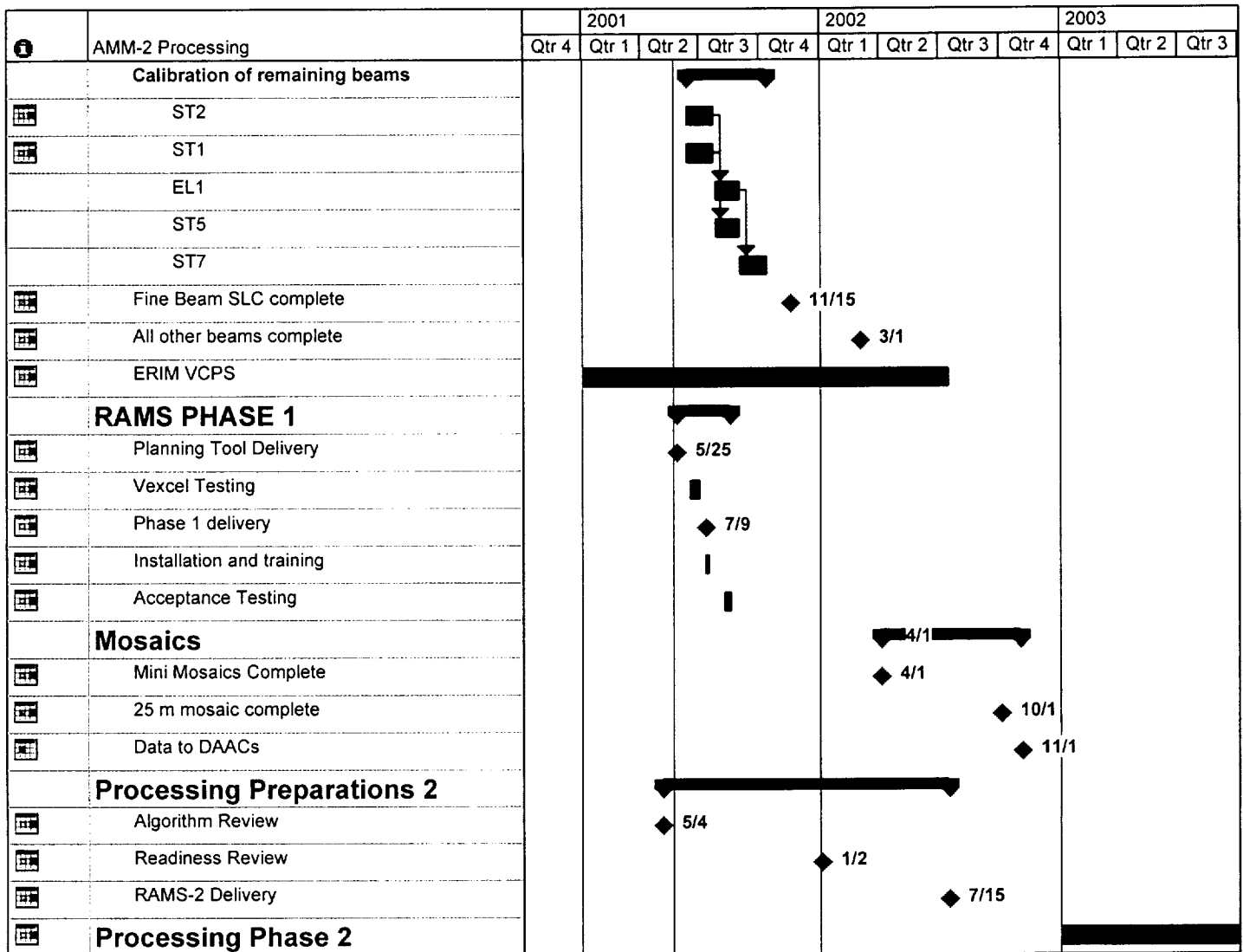
F1, mini-mosaics will be completed by mid-April 2002. Test products will be delivered to the AMPG for comment and review.

A status review on RAMS-2 Phase 2 will be held at Vexcel in January 2002. An AMPG meeting will be convened as a follow-on.

AMM-2 results will be presented at the International Glaciological Society Meeting to be held in Greenbelt, Maryland in June 2001.

7.0 Project Time Line Through 2003





8.0 Budget

Attached is the Year-2. \$20k of the amount budgeted to OSU in the original proposal has been reallocated from personnel into hardware purchases (additional hard disks). The result will be a delay in hiring the second research associate to work on AMM-2 processing. In addition, Vexcel is requesting an \$180,000 augment to cover unanticipated expenses as described in section 8.1.

AMM-2 Year 2 Budget

Salary

Faculty (1)	30240 (3m)
Res. Assoc.-2	37800 (12 m)
Res. Assoc.-2	28868 (9 m)
System Manager	31500 (12 m)
Secretary	500 (.25 m)
Benefits	32099
Grad Students (2)	28000 (24 m)
Benefits	308
Total Salary	189,315
Equip Maint	10000
Travel	20000
Misc Supplies	1939
Communication	1000
Publication Costs	1000
Total Direct Costs	\$223,254
Indirect Costs (46%)	\$102,697
Equipment	\$114,000
Subcontracts (Vexcel)	\$313,000 (see section 8.1 for augment request of \$180000)
Total Costs	\$752,951 (pending decision on Vexcel augment)

8.1 Vexcel Budget Augment Request

18 May 2001
Dr. Ken Jezek
Byrd Polar Research Center
Ohio State University
1090 Carmack Road
Columbus, Ohio 43210-1002

Dear Dr. Jezek,

Vexcel Corporation has been under contract to Ohio State University for the development of the RADARSAT Antarctic Mapping System 2 (RAMS-2) workstation. RAMS-2 will be used by the Byrd Polar Research Center, under your direction, to process the Modified Antarctic Mapping Mission (MAMM) data collected in the fall of 2000. We are currently in the second year of this multi-year development effort.

As we have discussed, there have been several increases in the scope of the work Vexcel has had to contend. These increases have made it impossible for Vexcel to complete the development of the RAMS-2 according to the original budget as requested in late 1999. A complete description of the history leading up to the current situation has been documented in a Vexcel Corporation memo dated 20 April 2001, addressed to the NASA program manager Dr. Waleed Abdalati. In summary, the following four out-of-scope tasks are the main reason for the budget short-fall:

1. Accelerated development schedule
2. Augmented requirements placed on the RAMS-2 system, due to unanticipated nature of MAMM data and unforeseen development efforts,
 - a. Requirement to form Mini-Mosaics.
 - b. Requirement for developing data ordering and frame planning software
 - c. Requirement to plan and process "triplet" interferometric data
 - d. Requirement to perform Doppler filtering on ASF processed data to make images suitable for RAMS mosiacking.
3. Late reception of test data,
4. Uncosted RAMS-1 maintenance effort combined into RAMS-2 development effort

Vexcel has estimated that the development impact, spread over approximately 18 months (from January 16, 2001 to July 15, 2001) is \$180,000. This corresponds to an

augmentation of \$10,000 per month. We request that all 18 invoices (starting with invoice of February 15, 2000 and proceeding through July 15, 2000 be augmented by this amount (\$10,000). This would require a correction to the invoices already submitted to date.

Sincerely

Richard E. Carande
Vexcel Corporation

